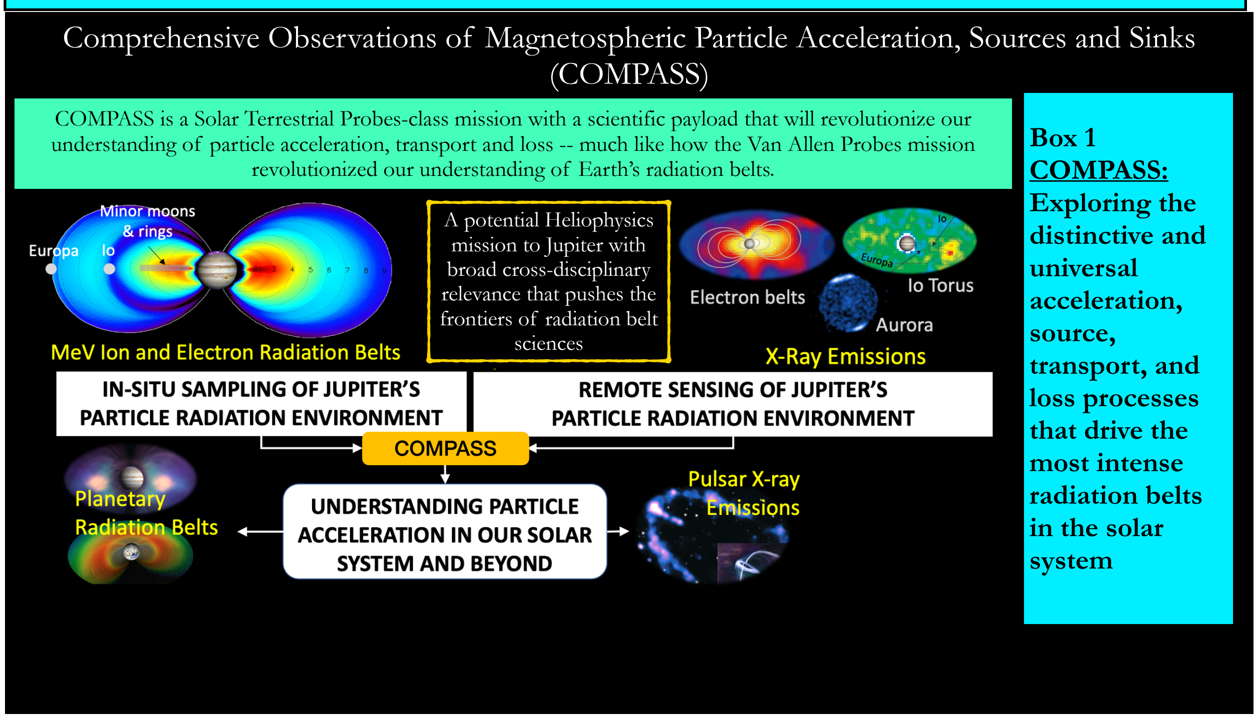
Comprehensive Observations of Magnetospheric Particle Acceleration, Sources and Sinks (COMPASS)
Pre-study Report

Goals and Objectives

The Comprehensive Observations of Magnetospheric Particle Acceleration, Sources and Sinks, or COMPASS for short, mission is a dedicated Heliophysics mission to Jupiter with broad cross-disciplinary relevance. The fundamental science strategy of COMPASS is to explore the distinctive and universal acceleration source, transport, and loss processes that drive the most intense radiation belts in the solar system. Building on experience and insights gained from the Van Allen Probes mission, which revolutionized our understanding of Earth's radiation belts, COMPASS will visit Jupiter, the solar system's most powerful natural particle accelerator. To achieve this, we parse this goal into four science objectives:

1. Reveal the processes seeding Jupiter's uniquely intense radiation belts
2. Discover how Jupiter accelerates charged particles to such exceptionally high energies
3. Reveal the loss processes of relativistic charged particles in Jupiter's magnetosphere and resulting X-ray emissions
4. Discover how moon and ring materials in the Jovian space environment help create the radiation belts even though they simultaneously limit them



Architecture

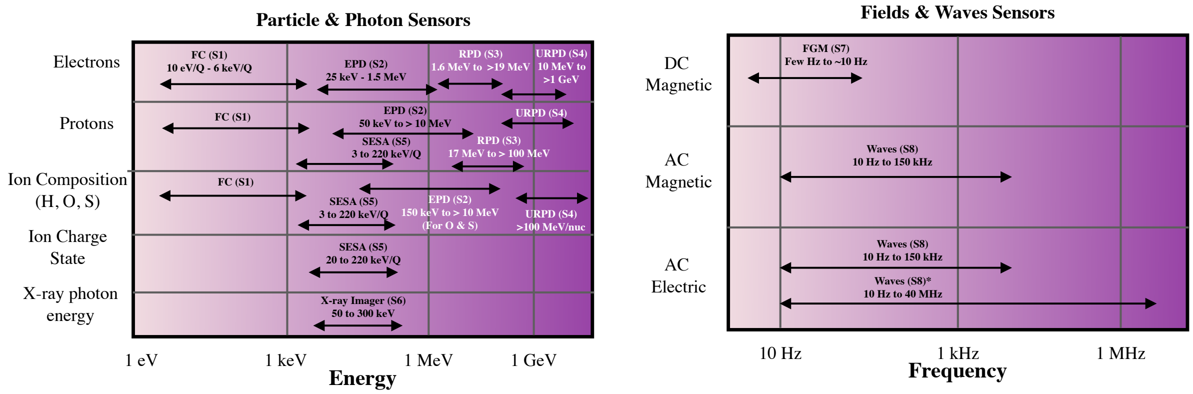
Addressing the proposed science strategy (see box 1) is critical to the success of Heliophysics in the next decade because it will expand our knowledge of radiation belt acceleration and general processes in extreme magnetospheric systems, a truly Heliophysics-focused science goal with broader impacts for both Planetary Science and Astrophysics. To resolve the most critical science questions, we propose a Jupiter equatorial-orbiting mission that makes several deep dives into the largely unexplored heart of its radiation belts, i.e., < 2 Jovian radii (R_J), with a uniquely comprehensive suite of instruments that will measure the charged particles (electrons and ions – including mass and charge-state composition, with novel methods to resolve the >10 MeV energies), field and wave distributions, and X-rays generated from radiation belt particle interactions. While constraints to these populations do exist and have been key for scientific analyses to-date, currently-available data are largely based on indirect means (integral in-situ observations, often with known or uncharacterized contamination and high backgrounds, and remote synchrotron measurements; e.g., Nénon et al., 2017; Hao et al., 2020; Kollmann et al., 2021). Table 1 is our proposed trade matrix outlining mission design parameters and relevant trades to explore during the proposed COMPASS mission concept study.

Table 1: Preliminary Design Parameters and Trade Spaces

Design Parameter	Initial Baseline	Trade Space	Impacts
Orbit	Equatorial ~2 x 29 R_J; Earth-pointed spinner	Orbit inclination; increase apoapsis, variable periapsis; Sun vs. Earth pointed	Science; propulsion; radiation; mission lifetime
Radiation	Centralized vault	Shielding mass & composition, radiation-hard components, instrumentation design	Mission lifetime, measurement SNR, payload mass
Mission Lifetime	> 10 orbits	≥ 3 months to to > 1 year	Temporal characterizations; mass and power
ADCS	Thrusters vs. magnetotorquers	Examine use and efficiency of magnetotorquers in the strong Jovian magnetic field	may save delta-V and facilitate routine despin for COMM to Earth
Power	Solar arrays	Roll-out vs. rigid panels	Drives science payload capabilities & mission lifetime
Communications	HGA w/ direct- to-Earth downlink	HGA size vs. data rate; can comm link close while spinning?	Power & mass
Thermal	Integrated approach with central area to heat electronics	Passive vs. active	Power depending how much passive heating is required
Instrumentation	All instruments listed in Fig. 6 are included	Descope one or both baseline instruments listed in Fig. 6, rely on existing Jupiter mission measurements & Earth-based remote sensing to retrieve missing science measurements	Science; Increased allocation for radiation shielding and power per instrument, ΔV
Background suppression	Heavily shielded instruments	Use higher coincidence schemes, which lead to a net mass reduction and/or increase signal to noise.	Science, power, mass
Magnetic cleanliness	URPD mass spectrometer may have strong stray fields	Reduce stray fields vs. studying impact on other measurements	Science, mass

Science Payload

To address its science goals, the proposed COMPASS study will target the preliminary payload outlined in Fig. 1 and summarized briefly below; it must be emphasized that the instruments listed in Fig. 1 are only representative of notional high-heritage instruments that could be used for the COMPASS mission. Because of Jupiter's intense radiation environment, we will determine what kind of shielding is required for the different instruments and if additional mitigation is needed. Examples of additional mitigations include robust coincidence functions that can greatly reduce backgrounds without the need of extra shielding mass. A high-priority task for the proposed study will be to assess the resource requirements for these instruments versus their performance versus the science goals outlined above. Any requirements for enhancements or augmentations to achieve science closure will be identified and considered in trade-studies balancing performance, technology readiness, cost, and resource demands; this may include consideration of whether additional and/or alternative instruments may be feasible with a specific emphasis on smaller and simpler instruments that may sacrifice capability.



Code	Description	Representative sensor	Est. mass & power	Requirement
S1	Faraday Cup (FC)	Europa Clipper PIM (Grey et al., 2018)	4 kg / 4 W	Threshold
S2	Energetic Particle Detector (EPD)	Juno/JEDI (Mauk et al., 2017)	6 kg / 2 W	Threshold
S3	Relativistic Particle Detector (RPD)	Van Allen Probes/REPT (Baker et al., 2013)	13 kg / 6 W	Threshold
S4	Ultra-Relativistic Particle Detector (URPD)	Mini-PAN (Wu et al. 2019; Ambrosi et al., 2019)	20 kg / 20 W	Threshold
S5	Suprathermal ElectroStatic Analyzer (SESA)	Cassini CHEMS (Krimigis et al., 2004)	6.5 kg / 10 W	Baseline
S6	X-ray Imager (Imager)	AEPEX X-ray imager (Marshall et al., 2020)	6 kg / 10 W	Baseline
S7	Flux Gate Magnetometer (FGM)	Juno/MAG (Connerney et al., 2017)	1 kg / 2 W	Threshold
S8	Plasma Electric & Magnetic Waves (Waves)	Juno or Van Allen/Waves (Kurth et al., 2017; Wygant et al., 2013)	10 kg / 6 W	<100 kHz Threshold; > 100kHz Baseline*
Total			Mass: 66.5 kg; Power: 60 W	

Figure 1: Science payload

Enabling Technologies

The initial architecture considered does not include any mission critical technologies below TRL6 and the instrumentation and spacecraft subsystems to be considered are all high-heritage. The mission could be designed using currently-available solar arrays; however, the ability to use rollout solar arrays or a novel configuration of rigid panels may improve the end-of-life power for this and future missions to deep space. Though not required, the proposed study will look at the potential changes in design parameters from these technologies.

Cost Estimate

The announcement of opportunity encourages innovative missions that cannot be accomplished on a Medium-class Explorers budget ($250M, phases A-F and excluding launch costs) and notes that the Decadal Survey is likely to permit a small number of larger missions (>$500M). A rough order of magnitude (ROM) cost evaluation was performed for completeness and compliance. Fortunately, the NASA Planetary Science Division recently selected the Io Volcano Observer (IVO) as a Discovery mission (cap <$500M) for Phase-A development. The APL-led IVO mission is the basis for estimating the cost of COMPASS. The ROM cost estimate for COMPASS is >$500M and is comparable to the Van Allen Probes mission. The estimate is for FY22$ and does not include a launch vehicle. Additionally, the concept includes all baseline instruments in the parametric modeling. We will require early costing estimates in the design study to inform the payload trades as well as continuous, near-real-time costing estimates and subsequent iterations and refinements.